The Institute of Physics

BULLETIN

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The Bulletin is published by The Institute of Physics for circulation to its members ; copies should not be placed in libraries.

Notices to Members

Nominations to the Board

Fellows and Associates have already received the Board's nominations for the vacancies which will occur on the Board on September 30 next. These will be for the offices of President, Honorary Secretary and Honorary Treasurer. There will also be one vacancy for a Vice-President and two for Ordinary members of the Board. The Board's nominations for these offices are as follows :

President : Mr. O. W. Humphreys
Honorary Secretary : Professor F. A. Vick
Honorary Treasurer : Dr. James Taylor
Vice-President : Dr. D. P. Dudding
Ordinary members of the Board :
Dr. L. R. G. Treloar and Mr. G. W. Warren

A further nomination for Ordinary Member of the Board has been made in accordance with Article 48. Mr. M. Milbourn has been nominated by Dr. R. E. Bastick (*Associate*), Mr. V. E. Gough (*Associate*), Dr. T. L. Richards (*Fellow*), Dr. W. T. Roberts (*Associate*) and Mr. E. C. Williams (*Associate*). The three nominations for the two vacancies for Ordinary Members of the Board are, therefore :

M. Milbourn, B.Sc., A.R.C.S., F.Inst.P., Assistant Research Manager, Imperial Chemical Industries Ltd., Metals Division, Birmingham ;

L. R. G. Treloar, D.Sc., F.Inst.P., Senior Physicist, British Rayon Research Association, Manchester ;

G. W. Warren M.B.E., B.Sc., F.Inst.P., Group Leader, Research Laboratories, The General Electric Co. Ltd., Wembley.

Ballot papers have been circulated to Fellows and Associates. Completed papers should be

sent by post to the Institute's House to be received on or before July 15 or they may be handed in to the scrutineers at the Annual General Meeting that is to be held at the Institute's House at 5 p.m. on July 16.

Attendance at the meeting is restricted to Fellows and Associates.

Salary Inquiry

The Board has authorized the Deputy Secretary to conduct a fourth inquiry into the salaries and other emoluments received by Fellows, Associates and Graduates of the Institute. Inquiry cards will shortly be circulated to all members of these grades resident in Great Britain. It is particularly hoped that there will be a good response from members of all levels of seniority. In the past, more than 70 per cent of the cards sent out have been returned. The published reports of the three previous surveys have been widely welcomed and have been of great value to physicists and their employers. Information supplied is treated as personally confidential to Dr. H. R. Lang and Mr. N. Clarke and is not divulged by them except in statistical form.

The opportunity has been taken of collaborating with the Royal Institute of Chemistry which is conducting a similar survey. The inquiry cards have been designed so as to obtain corresponding data in the two surveys, and it is intended to produce reports which will enable the data for chemists and physicists to be compared easily.

Journal Supplement on The Physics of Nuclear Reactors

All members of the Institute are entitled to receive one copy each, for their personal use, of the Supplement No. 5 to the *British Journal of Applied Physics* at the reduced rate of 15s. including postage (retail rate 25s.). An order form is enclosed with this *Bulletin*.

Those who take this Journal are reminded that they will automatically receive a copy (in paper covers) as part of the volume, without extra payment. The Supplement will contain the papers (other than Professor Peierls' discourse) presented at the Institute's Conference on "The Physics of Nuclear Reactors" (details of which were in the February *Bulletin*) held earlier this month, and the discussion on them. It is hoped to publish it well before the end of the year.

Group Subscribers

The Board has accepted for a trial period of two years a recommendation of a meeting of Group representatives that there should be a new form of membership of the Institute's specialist Groups. This will be termed Group Subscribership and is intended for those who are not eligible for any grade of membership of the Institute other than that of Subscriber. Group Subscribers will be entitled to become members of *one* Group and to receive its notices and circulars, to attend its meetings without additional charge and to be able to hold office in the Group, provided that not more than one office is held by a Group Subscriber or a Subscriber. Group Subscribers will not be entitled to receive Institute publications at privileged rates nor to receive the *Bulletin*. They will, in fact, receive no privileges beyond that of membership of one Group.

Symposium on Magnetic Resonance

A Symposium on Magnetic Resonance is being arranged by the Liverpool and North Wales Branch of the Institute at the University College of North Wales, Bangor, on Wednesday and Thursday, September 26 and 27, 1956. Lectures will be given by Dr. B. Bleaney (University of Oxford) on "Free Atom Resonance," Dr. J. G. Powles (Queen Mary College, London) on "Spin Echo Techniques," Dr. R. E. Richards (University of Oxford) on "Magnets," and Professor E. R. Andrew (University College of North Wales, Bangor) on "Nuclear Magnetic Resonance work and other research at Bangor."

At the Symposium consideration will be given to the formation of a Group to provide future occasional meetings.

Further particulars of the Symposium may be obtained from Professor E. R. Andrew.

Vol. 7, July, 1956

The Teaching of Atomic and Nuclear Physics*

By Professor W. E. BURCHAM, M.A., Ph.D.,
and Professor P. B. MOON, M.A., M.Sc., F.Inst.P., F.R.S.
(*University of Birmingham*)

AMONG the problems which come naturally to mind in connection with the teaching of modern physics are :

(*a*) what people should be taught atomic and nuclear physics, particularly in view of the large expansion in technological education which has been asked for by committees on scientific manpower ?

(*b*) the extent to which atomic and nuclear physics should be based on a thorough course in classical physics,

(*c*) the connection of modern physics with other subjects, both in pure and applied science,

(*d*) the form of a typical university course.

Although these headings do not by any means exhaust the subject under discussion they at least touch on many of the points which are of current interest. Probably there exist statistical surveys which answer many of the questions proposed here. Such statistical answers are not always very helpful and the purpose of the present talk is to give a rather more personal point of view, based on some years of experience in the teaching of atomic and nuclear physics at university level.

The short answer to the question of whom to teach is that everybody should be taught these subjects to some extent. The present century is the age of technology as fully as the 19th century was that of the Industrial Revolution and just as the Mechanics Institute of the last century sought to put current scientific knowledge within reach of all so must our own universities, colleges and schools cater for a wide public interest. The laws of nature which have been revealed by progress in atomic and nuclear physics are as important for the future of the human race as the laws of man, and their consequences are a good deal more predictable. They summarize a body of knowledge of which at least part should be within the grasp of every educated person, although it would be unreasonable to expect that everyone could accord them a full scientific appreciation. It is interesting to reflect in thus suggesting a wide diffusion of knowledge of atomic and nuclear physics that these are not really young subjects. Nuclear physics is over fifty years old, half as old as thermodynamics. The name " electron " was given to cathode rays only eight years after Maxwell published his theory of light and seven years before the discovery of Hertzian waves. We must remember too that more *detailed* physics has been discovered in the last fifty years than in all previous time, and that much of this stems from the study of the subjects which we have under discussion.

The child of 15, leaving school, will know something of many of the more spectacular advances of modern physics from films, television, newspapers, science fiction or perhaps just by hearing others talk about them. It would seem right that his school course should at least refer to such things as atoms and electrons, and that nuclear energy should be added to the conventional list of power sources. Even primitive races often worshipped the sun and our reverence need not be decreased by knowing more about it. Many children will afterwards join extra-mural classes or enter technical colleges or otherwise participate in further education

* Presented by Professor W. E. Burcham at a meeting of the Education Group on April 5, 1956.

and for them there will be opportunity to acquire greater detail. This general field of instruction is, I think, to be dealt with in later lectures to-day and I pass on therefore to the university graduate. It is unfortunate that many of the Arts Faculties of the universities in this country regard science as a necessarily incomprehensible burden which should be avoided at as early an age as possible. Some are more enlightened and, in at least a few, lectures on modern scientific developments have been made available and have received enthusiastic support. There seems little doubt that the average Arts student welcomes information on atomic and nuclear physics provided that it is presented in the right way and I must admit here that there are probably not many people who have the gift for presenting these rather difficult and technical things in a way that will really stir the enthusiasm of somebody who comes to them with little or no scientific training. But there is no doubt that it can be done and should be done and will probably in the future stimulate more than a few arts graduates to look for employment in industry or other scientific occupations. Apart from this I should emphasize again that modern physics is part of our contemporary heritage and can be both taught and appreciated for its cultural value as distinct from its more narrow vocational function. This is the reason for the interesting general course in arts and science which is given in the first year in the University College of North Staffordshire, a course whose development deserves to be watched with the greatest interest by all university authorities. Nor should it be thought that the more traditional career of the average arts graduate can remain wholly uninfluenced by developments such as those in atomic energy. Already the implications of atomic power are being felt in many different activities—insurance and architecture to mention only two.

The graduate in science at the pass or honours level usually intends to make his career either in the teaching or in the practice of science. He should be no less conscious than his fellow student in arts of the cultural value of modern physics but he also requires a specific vocational training in his chosen interests. His detailed study will already have started at school and will continue for some six or seven years, during which the properly trained physicist would find time for lectures on the historical background of his subject. And since he is a man, as well as a physicist, there should be some attention to the humanities. Among graduates there is the relatively small but rather interesting class of people who make academic research their career. For them the learning of atomic and nuclear physics is never complete, but much of it they must teach themselves, individually or in the academic seminar. We are more concerned here with those honours students, forming the large majority, who enter some branch of industry or the teaching profession. The former need above all an understanding of modern techniques; the latter need sufficient appreciation of the principles and achievements of atomic and nuclear physics for them to be able to communicate their interest and enthusiasm to others. We are also concerned with the older graduate who may find himself left behind by the rapid advance of techniques and who returns to a university or technical college for a refresher course to bring himself up to date. The teacher of atomic and nuclear physics is therefore called on to deal with many types of student and his method of approach may have to depend much on the common background of those whom he teaches. One of the most important elements in this background is the body of knowledge usually described as classical physics.

For the simple reason that modern physics grew out of preceding knowledge it is obvious that a thorough grounding in classical physics is indispensable to a proper understanding of the atom and of the nucleus. It would hardly be worth making this point if it were not for the fact that physics as a whole has grown so greatly that something has to be sacrificed in most university courses. I wish here to make the plea that this something should not be any of the great subjects of classical theoretical physics — mechanics, thermodynamics, or electrodynamics — and that neither should it be practical physics which is

normally largely of the classical variety.

So many of the practical benefits of physics, by which interest in the subject as a whole may be sustained, are still of a purely classical nature ; one is only infrequently aware in everyday affairs of the atom or the nucleus. It is important in the early stages of the education of a physicist that these practical applications should be emphasized by visits, for instance, to industrial plants, power stations and research establishments. At the grammar school stage, such activities should be sufficient to look after the desirable general growth of interest in the subject. The periods of formal teaching may then be used to lay the foundations of a good understanding of the classical theories and experimental methods, both of physics and chemistry. It is not helpful at this stage to qualify every statement by a remark that this looks different in wave mechanics. The schoolboy is generally quick to detect and also to resent any attempt to confuse an issue. And the great growth of the principles and applications of atomic theory in the 18th and 19th centuries should provide more than enough stimulus for the active mind. Probably the atom will first appear in the chemistry course and it will be up to the physics master to see that he is not left too far behind He may get in first with the electron but neither of them should in my opinion have any dealings, at least until towards the end of the sixth form course, with the quantum theory in any of its manifestations.

At the university much of the classical story will be retold with greater emphasis on detail and analysis, and 19th century physics should be consolidated as soon as possible. The first year course may include an introduction to modern physics, perhaps subdivided for honours students and those taking physics only as a subsidiary subject. But again, the main emphasis should be on classical work, particularly in the practical laboratory, since the vast majority of physicists in industry do not need to think of a current as a stream of particles and certainly not as a procession of waves while for the biologist such a concept might well be an embarrassment.

In the second year of a physics course emphasis should be placed on classical mechanics and electrodynamics, including radiation theory. There should be a serious introduction to the study of ions in gases, simple radioactivity and an introduction to the quantum theory with applications to the hydrogen atom, spectroscopy and the solid state. This is one of the most important courses of all and deserves adequate provision of lecturing time. The lecturer can hardly fail here to engage the interest of his students. His success or otherwise will be judged by the extent to which they read for themselves in the many excellent books on the subject. There is perhaps some danger of mental indigestion at this stage particularly if mathematical proofs are too freely used but this danger can be minimized if the classical foundations are firmly laid. It is no service to the student to present him with an inadequate story and it is important that even if full rigorous proof cannot at this stage be given, at least valid classical analogies should be used so that later on nothing really needs to be unlearned.

In the third and final undergraduate year the physicist, in addition to further consolidation of what has gone before, should be introduced to nuclear physics in its more descriptive and less analytical forms. Main attention should be given to the techniques of the subject and to the historical development and the student should particularly be encouraged to make the rough type of calculation which is often so useful in this field. It is idle to pretend that nuclear theory can be successfully taught in the average undergraduate course and in my opinion it is best to avoid it altogether and to let the nuclear physics course be itself an introduction to more rigorous postgraduate instruction. A most valuable subject to introduce at this stage would be "Techniques of Research"—essentially a discourse on the properties of materials, instrument design and workshop practice.

Postgraduate courses for those embarking on a research degree or wishing to enter the research departments of Government establishments or industrial firms, should be based on the preceding undergraduate courses and

grow naturally out of them. Nuclear theory and solid state can best be taught at this stage since the student, without the embarrassment of an immediate examination and with the advantage of more intimate contact with the staff, may develop rapidly. Many will find at this stage that they are able to appreciate a detailed course in quantum mechanics and the value of this is very great indeed. It is greater still if opportunity is given for actual practice in the solution of problems under supervision.

The rate of advance in atomic and nuclear physics is so large that practically nobody can hope to keep abreast of new developments himself. I think that nearly everybody would benefit from attending a course of lectures every five years or so in which the nature and significance of recent developments were reviewed and set in perspective with physics as a whole. I mean by this something more lengthy and more formal than the usual conference type of meeting which suffers from intense concentration. Such courses could be easily provided by departments of universities in which postgraduate courses had been established. The ordinary post-graduate courses might also be planned to provide for graduates in subjects other than physics, although this might mean that the nuclear engineer emerging from them would lack knowledge of some branches of classical physics.

Physics is of course required to a greater or less degree in the study of other scientific subjects. One result of this is that the sequence of teaching which I have outlined is regularly undermined by the chemist and, to a less extent, by the electrical engineer. The chemist needs the ideas of atomic theory, the properties of ions and electrons and the results of spectroscopy long before the physicist and does not mind that subjects such as geometrical optics or the thermodynamics of radiation have not been taught. Then again the electrical engineer speaking of radio valve design takes the properties of electrons for granted without being too much concerned as to how these were established. Logically it would be best to reach physics first and then the other things but timetable difficulties alone would prevent this. Physics too is probably the hardest of all these subjects to learn and needs most care and attention while it is being learnt. The solution to this problem of inter-relation seems to lie in regular and detailed discussions between the staffs of the college or university in which the several subjects are being taught. Such discussions, it might be hoped, would lead to better co-ordination to the mutual advantage of the several departments. Atomic and nuclear physics in particular would gain much by the introduction of examples of application in other fields of research.

It should also not be overlooked that the teacher of atomic and nuclear physics has himself a problem of correlation. Atomic and nuclear physics have much more in common than is perhaps usually realized. For instance, the semi-classical analogies often used in the theory of radiation apply equally to both and opportunity should not be lost of drawing attention to this. Then again atomic and nuclear shell models derive from the same general point of view and the analysis of elastic and inelastic collisions is, of course, basically the same in both subjects. The differences between them are largely matters of scale rather than of kind and a skilful teacher can do much to draw the two subjects together if this is realized.

Perhaps now I may illustrate some of my remarks by giving an outline of a typical university course designed primarily for those who have reached advanced level in G.C.E. in at least physics and one other scientific subject, with it is hoped some knowledge of the calculus.* There is no doubt that it would be much easier for everybody if the course were planned on a four-year basis, but for the present purpose I shall assume that only three years are available.

The first year is devoted mainly to consolidation of school work and to subsidiary subjects. This is intended to provide a fairly broad scientific basis on which the specialized work of the following two years may be built.

* The Faculty of Science admission requirements at the University of Birmingham at present call for three subjects at advanced level, one of which shall be Mathematics for students wishing to read for Honours in Physics.

Present day technical literature demands knowledge of languages and a good deal of time is devoted to this in the first year. Similarly the technique of mathematical analysis is extremely important and is encouraged at this time.

In the second year atomic physics is introduced in 20 lectures followed by 20 lectures on spectroscopy. These lectures trace the steps leading to the development of the Rutherford-Bohr atom and discuss the application of this theory to the interpretation of spectra. Although it is dangerous to place too much emphasis on the idea of a Bohr orbit, this idea is more easily grasped by the student than that of a wave mechanical probability distribution. The best compromise between an easily grasped picture and what seems to be the true theoretical approach is probably to start off with orbits and to indicate at each stage the modifications introduced by wave mechanics. As the course proceeds, more and more use can be made of the wave mechanical ideas and symbols although in the second year it is still too early to present the formal wave mechanical theory. Concurrently a sound knowledge of classical mechanics including, if possible, generalized mechanics is established via the department of mathematics. This is important because it makes the transition to the modern theories of relativity, statistical mechanics and wave mechanics much easier. These subjects are introduced and treated in detail in the third year in which are also included lectures on theory of the solid state. The course is designed so that as far as possible the fundamental principles are covered before applications to particular problems are needed. The third year also includes 32 lectures on descriptive nuclear physics in which only the simplest theoretical ideas are introduced.

Towards the end of the third year a smaller number of deliberately advanced lectures are given with the object both of stimulating the interest of the class as a whole and of attracting students into one of the related fields of research. In the particular course of which I am speaking such lectures have been given on luminescence and high energy nuclear physics.

Throughout the second and third year of this course there is associated practical work which is designed to train the student in the general techniques of physics, to enable him to solve practical problems which he meets and finally to show him the application and the methods of atomic and nuclear physics in modern research. As a help to this, many undergraduates spend a short time working with graduate students in the research laboratory on some simple problem. The postgraduate courses for the M.Sc. and Ph.D. degrees then naturally grow out of the third year of undergraduate teaching. In these courses instruction is given in the techniques of glass-blowing, workshop practice and electronics, while the theoretical course takes up the formal development of quantum mechanics and theoretical nuclear physics.

I think perhaps that I have said too much about the academic physicists ; but this is deliberate because perhaps the main difficulty in modern physics is conceptual. The student is apt to be suspicious of things like wave equations in three dimensions and it is the business of the teacher to show how modern methods have grown out of those which have preceded them. And he must also show how technological advances result in a situation in which both physics and technology are in a continual state of evolution, with the one fertilizing the other. Successful teaching in atomic and nuclear physics demands patience and tolerance at all levels and for most students a high degree of concentration and wide general reading. Many students will be helped by the evolution of special courses and this is particularly true of the industrial physicist who will not in general have time for the course which an academic physicist would often like to give him. We shall therefore certainly see more and more atomic and nuclear physics taught not only in universities but in technical colleges and institutions such as the Harwell Reactor School which have been designed for special purposes. It is to be hoped that in the great expansion of this teaching, time will be found for some attention to be given to the general principles and laws of nature on which modern physics is based.

Ethics and the Scientist

A joint meeting of the Education Group and the Manchester and District Branch of the Institute was held in Manchester on March 24, 1956, as a discussion of " ethical problems confronting a young scientist in the atomic age " and was attended by about 200 people. Sir Eric James, High Master of Manchester Grammar School, was in the Chair. Addresses were given by Mr. G. N. Burkhardt, a research student in mathematical physics in the University of Birmingham, and Dr. P. Lord, of the British Rayon Research Association, representing the younger scientists, and by Professor H. Levy, formerly Head of the Department of Mathematics in the Imperial College of Science and Technology, London, and Professor M. Polanyi, F.R.S., Professor of Social Studies in the University of Manchester and formerly Professor of Physical Chemistry in that University. The following is an edited version of the addresses and discussion.

SIR ERIC JAMES : I am not a member of The Institute of Physics and perhaps I may say, therefore, what a very good idea it is to hold this meeting. The very large attendance which we have on a Saturday afternoon when the Grand National is on elsewhere shows how many of you have thought it a good idea, too.

I will introduce the speakers in the order in which they will speak. Mr. Burkhardt is a product of Manchester Grammar School and Oxford and he is now doing theoretical physics research at Birmingham. Dr. Lord was also at Manchester Grammar School and Manchester College of Technology, and he is now working for the British Rayon Research Association. Professor Levy has been, until last year, Professor of Mathematics at the Imperial College, with particular interest in aerodynamics. Professor Polanyi is very difficult to describe, because he is not only a very distinguished chemist but also a distinguished sociologist and philosopher.

The subject with which we are dealing is one of very great importance. I will not anticipate what they will say, but obviously in a world in which the power of science, the scope of science and the amount of science is increasing, and will inevitably increase as the years go by, the impact of that scientific work on the lives of all of us is also increasing.

That impact, as we know, raises for every one of us engaged in scientific work a number of problems of conduct, and The Institute of Physics with, if I may say so, great imagination, thought that it would be worth while to get two of the younger generation and two of the older generation, if I may so describe them, to talk about the problems which arise through the relations of science with ethical problems.

MR. G. H. BURKHARDT : My feeling, when I was first asked to speak here—and it still is my feeling—was that this is clearly a very important subject but that it is a very difficult subject on which to say anything concrete or constructive. But I think that if we can reach some agreement about what the problems are we shall achieve a good deal, for they are rather elusive. We all have some ideas on the effect which the existence of nuclear weapons and the importance of science in modern life has on the scientist, but to put them in precise terms is not easy. It is my function, and that of Dr. Lord, to raise the problems which we see rather than to attempt any comprehensive answers. No doubt the senior speakers will be able to do more in that direction.

I would group the problems about which I shall talk under two headings. There are those concerned with the welfare of humanity and there are those concerned with the welfare of science. A great difficulty arises in that the public is now very much aware of what goes on in science. This works in two ways. It is very much easier than it used to be to get money to do almost anything, but it means that the decisions affecting science are not entirely made by scientists, as they used to be in the period up to the end of the 19th century or perhaps up to the beginning of the First World War.

These developments in science are well known to the public. Surely the paramount problem concerning humanity is the manufacture and possible use of nuclear weapons. However, it is my feeling that the decisions on this subject are made primarily by the community as a whole. It affects the community as a whole so closely that it is no longer the preserve of the scientist to decide policy about the manufacture of nuclear weapons ; it is a political matter. The subject of this meeting being " Ethical problems confronting a young scientist in the atomic age," I feel that we should not primarily concern ourselves with the problems confronting the scientist which also face everybody else, but should confine ourselves to those problems specific to the scientist. I do not know whether that is a restriction which the Chairman wishes to impose, but that is the way in which I have interpreted the subject. We clearly cannot avoid many of the issues which are common to both, but in the time available I shall raise under this heading only a couple of problems which I think are specific to the scientist ; that is, to the man concerned with possible work on weapon research, and in particular on nuclear weapons. Clearly there are separate ethical problems involved for the man who has to decide, as I may, for instance, in two years time, whether to do National Service in the Armed Forces or in a research establishment of the Ministry of Supply. There is an ethical problem—I do not say especially for me, but in general—as to which one should choose.

Setting aside the popular feeling that it is a good idea for everybody to have experience of how unpleasant the Army can be, and discussing the problem merely on the assumption that if one believes in a national defence policy it is one's duty to assist it in the best possible way, there are, I feel, only two alternatives facing the man in that position. First, he may believe that it is wrong to prepare for war in any circumstances, in which case, I feel, he should be a conscientious objector ; he should not work at the research station and he should also be a conscientious objector to National Service. If, on the other hand, he believes that the policy of the Government is right, in the main, and that it is right to prepare for war as being the best means to secure peace, it is his duty to assist the defence programme in the way in which he will be most efficient which, for a scientist is, without doubt, to work in a scientific research laboratory.

This is an over-simplification, I admit, for many people believe that war with conventional armaments is conceivable because we are used to it, whereas war with nuclear weapons is too horrible to contemplate. We all have a horror of nuclear war, but unless we are quite convinced that the use of nuclear weapons would in all cases be wrong, we cannot say that no country should set about having the means to produce and deliver these weapons. I feel that it must be proved in all cases to be wrong, which puts the onus of proof on the abolitionists of nuclear weapons.

That is all I want to say on the rights and wrongs of doing weapon research. It is an enormous subject, which has been much discussed in the past and no doubt will be discussed a great deal more this afternoon. How far I go into it must be governed by the time available.

The second question, which is very much involved in the first, is that of security. By this I mean secrecy and the withholding of scientific information from the general scientific public on grounds of national security. This is a subject which it is difficult to talk about, because it is so diverse ; there are a thousand-and-one nuisances to every scientist concerned with it, none of which, by itself, is very important. Very few people deny the need for security granted the assumption that we are going to do scientific work for defence purposes. We are concerned with the agglomeration of rather small points, and it would be impossible to mention most of them in the time available, but one ties up with the second main topic which I shall raise, which is where modern developments affect the welfare of science rather than the welfare of humanity. It is a question of how the withholding of scientific information

from the general scientific public affects the progress and evolution of science, and the feeling of the scientist about his position with regard to his work. If I could elaborate this a little more, science, in general, grows by the person advancing a theory and set of experimental results, publishing a paper, and other scientists elsewhere checking the work, doing confirmatory experiments and trying to find out whether the predictions of the theory in fact held good. The whole thing goes into the melting pot of the whole scientific community and, gradually, in the course of time—it may be anything from a few months to many years—a general opinion comes to be held amongst scientists as to whether it is fundamental, or is true but not very new, or is nonsense. On this process the whole scientific development depends.

It seems to me that if in any one field, a large fraction of the information is cut off from this assimilation process, there is a very real danger that the process may not function properly. The most obvious things which will happen are that progress will go more slowly—this is not too serious—a wrong conclusion may be reached—this is not very likely—or that there will be a feeling of incompleteness on the part of the scientist working in that field through his not being able to see the overall picture of what is happening. I feel that there is this danger from security. I raise the point in order that the two senior speakers may comment on it. I would add that in nuclear physics it is no longer a serious problem ; the problems connected with nuclear weapons are not primarily those of nuclear physics. But I should have thought—although I know even less about this—that in the field of electronics or servo-mechanisms an enormous amount of work must have been done on guided missiles which must have produced fundamental new work, and that this is not available to civilian workers in these fields. Here quite serious effects may be felt.

This brings me to my second main topic. How have the new developments in the last twenty-five years affected the spirit and the way in which the scientist works ? As far as I can see, two things are now true of science which were not true fifty years ago : first it is very expensive, in general, and, secondly, it is closely tied up with the standard of living. The public knows that science can now contribute to raising the standard of living. The 19th century position, in which the scientist was somebody remote and the inventor was the one who contributed to one's well-being, has disappeared. The people who produce results now are teams of scientists. The division between pure and applied science has, in a sense, gone.

These two points bring two difficulties. First, science is expensive and money has to be found. Because science is tied up with economic standards, money is found ; and money is much more easily forthcoming. That brings with it what I consider to be a fundamental danger, that the control of science is in some ways passing out of the hands of the scientists and into the hands of the administrators, who are not always scientists ; and, finally, into the hands of politicians, who, in general, are not scientists.

To illustrate this by example, from the United States. Nuclear physics work depends very much on the building of large accelerating machines, which cost a great deal of money. This money is not, in general, given to the universities to use as they think most fit—in the United States almost universally and in this country generally it is given for specific purposes. This means that a scientist has to convince a non-scientist of the validity and hopefulness—and this often means the commercial prospects—of the work he is doing. There is a real danger in this. We must be fair by putting the compensatory advantage in that—I must stress the point again—more money is available ; and there is also a great deal of quiet duplicity on the part of authorities in giving money for research unrelated to the objects for which the money was donated. It continually amazes me to read the papers coming into our department on quite abstract subjects which are financed by the office of Naval Research of the United States Government. This is sheer philanthropy,

and the people who give money know what they are giving it for. This is very cheering, but the principle remains that the control of science is now very much in the hands of the people who provide the money. I feel that this is a danger.

Finally, with this change, the motivation of research may be changing. In the 19th century, we can say, the scientist's only motive in what he was doing was the same as the motive for climbing Mount Everest ; he climbed it because it was there and because it interested him. This is no longer so. There is a powerful economic motive. The scientist has no doubt that what he does will make a positive contribution to the welfare of the people, and we thus have an economic and social incentive as well as an academic one to work for science. It is important that we should decide the relative importance of these two incentives to each of us, because, if the economic incentive is the prime incentive, then surely it is right that a great proportion of the money should be spent on applied research. It is quietly accepted now that pure research pays in the long run, as the example I mentioned earlier illustrated, but surely the standard of living of the world could be raised very rapidly with the fundamental knowledge now available, if only it were applied skilfully. The standard of living of the people might therefore be raised fastest by spending a large fraction of the money on applied research.

If, however, one feels that the academic motives, which formerly were the only motives in science, are still as important as, or more important than, this, then it seems that the money available ought to be poured in more or less large measure into pure research. The dichotomy is partly obvious and, I think, not entirely false, and this is the question which I feel is most important to us as scientists.

There is, however, one other point, which may seem trivial, but which is of practical importance—the supply of future scientists. We are continually hearing of the shortage of science teachers of the requisite calibre at all levels. I should like to ask the senior speakers whether they do not think that it is the duty of all scientists to teach, say, one day a week and to swell the teaching population in that way. I am not suggesting that we should press-gang people into becoming full-time teachers ; no good teacher would be produced. But I know people in the universities for instance, who are not primarily interested in teaching—of undergraduates especially, but who do so and often extremely well because their salaries depend on it, and because they like the other aspects of university life. If they were in industry they would not in general teach. Could they and should they be given some encouragement to teach ? Could their employers be given some encouragement to give them time to teach? If this problem were solved, many others would seem less difficult.

Dr. P. Lord : I think the points which I wish to raise will appear to be much more mundane than those raised by Mr. Burkhardt and much less philosophical. As a young physicist who has spent a short time —a very short time, I must admit—assisting Britain's defence programme, I find that the ethical problems facing our profession to-day are very real. I envy those of my colleagues who think that these problems are mere figments of the imagination.

In the time at my disposal I can only deal briefly with some of the questions which are uppermost in my mind and hope that they are of general interest. Having myself been employed on research the ultimate aim of which was the destruction of my fellow men, I can appreciate the rather indifferent attitude which some scientists appear to adopt. When working on a small part of an extensive research programme, the end point is often overlooked. Suppose, for instance, you earn your daily bread by designing electronic circuits, using transistors or investigating the acceleration of atomic particles to higher energies, the end product of your efforts may be a guided missile or an atomic bomb. On the other hand, it could be an electro-encephalograph or X-ray machine for deep therapy. In other words, it is the financial supporter of the enterprise

who determines the nature of the final product. So the scientist must decide whether or not he has a right to choose the purpose to which his researches are put.

If a scientist feels that he has a moral responsibility to society with regard to his discoveries, then he should clear his conscience more by trying to persuade his employers to put his work to peaceful uses than by refusing employment altogether. What I am suggesting is that he should make an active rather than a passive approach to these problems.

This leads naturally to the question as to whether or not a scientist is morally responsible for the production of weapons of mass destruction. Personally, I do not think he is. But he is certainly more responsible than an ordinary member of the general public, because he is in a position to appreciate the destructive power within his grasp. Too often he places the onus of responsibility upon his political leaders, or, if you like, his Government. Of course, the scientist is perfectly free to choose the type of work in which he wishes to participate, assuming that he has fulfilled his National Service obligations.

This reveals a certain group who, to me, appear able to change at will the foundations upon which they build their moral principles. Why is it that a young physicist could refuse to assist in the development of a hydrogen bomb but would not hesitate to answer the call to arms ? Is there any difference in principle between dropping an atomic bomb and killing one's enemy with a rifle bullet ? Is it the principle which matters ? Or should degree be taken into consideration ? Shall we say that it is legitimate to manufacture a small, conventional, aerial bomb but not a nuclear bomb ?

To carry this a stage further, shall we raise an outcry against blowing the world to pieces but condone a nice, good old conventional war ?

But if we pass over this problem for a moment and decide that it is necessary to arm against potential enemies, then the defence should be the very best which technical brains can conceive. To me, therefore, it is correct to say that any man refusing to take part in the defence programme is just as much a conscientious objector as a man who refuses to shoulder a rifle. Since the possibility of world war cannot altogether be ruled out, shall we tell the remainder of the community the consequences which would follow the dropping of a hydrogen bomb on one of their cities ? Or shall we permit them to continue to live in a fool's paradise, completely oblivious of the disastrous effects which would undoubtedly follow such an event ?

The question is not analogous to that which the doctor must ask himself before deciding whether to disclose to his patient, or not, the presence of a malignant growth. To the person whose days are numbered, this witholding of information may prolong his happiness. This is not so in the case of the bomb, where complete knowledge of the facts, unpleasant though they may be, may encourage the public to ensure that there are no further wars. After all, they, along with the controlling minority, the scientists, could take what is in effect strike action. How this could be achieved I do not know.

This, I feel, would lead to mass unemployment, and are you, as scientists, prepared to go hungry if everlasting peace can be guaranteed ?

Somewhat changing the topic, I come to the vexed question of security, on which Mr. Burkhardt has already said a few words. As long as defence is necessary, it is desirable, in my opinion, to prevent information from being passed to potential enemies by restricting publication and discussion of results. Many scientists object most strongly to this, and yet if employed in private industry would they part with the company's secrets ? Do they not owe some sort of allegiance to their employer, whether it be the Government or private industry ? If they are not prepared to make this sacrifice I suggest that they are better employed elsewhere.

On the other hand, it can be argued that one represents national security, which Mr. Burkhardt has dealt with at length, and the

other the interests of a private company and the two bear no relation to one another. I personally do not support this latter argument.

Turning to one of the less glamorous aspects of science, the education of the younger generation, graduates leaving university often express a desire to teach if—and it is a big "if"—the emoluments enabled them to live free from financial worry. The men and women who feel that they have a flair for teaching are the most desirable, because they probably possess the gift of being able to mould the young person's mind in such a way that it is capable of assimilating knowledge and, later in life, applying it. Are they, then, under a moral obligation to teach, irrespective of the poor financial reward, in view of the increasing shortage of science teachers?

Clearly, as has been said, the problem cannot be solved by all scientists taking part in education, because, as we are all fully aware, the outstanding scientist is not necessarily the ideal tutor for the adolescent.

PROFESSOR H. LEVY: It is very significant that The Institute of Physics, which is primarily concerned with essentially scientific problems, should run a conference for the discussion of moral, philosophical and even political issues, because that fact touches very closely the meaning of a scientific education. Whether or not the latter gives a broad basis for human and social understanding, the fact remains that these issues are forced into the arena of discussion, and this afternoon the speakers have stepped out of the narrower grooves to which they normally restrict themselves.

The first difficulty which both we and the younger generation experience is to emancipate ourselves from the restricted view of the motivations which we, as *individual* scientific workers, express in pursuing our work, and to see ourselves as a group undertaking a certain kind of social activity. Two rather different questions are involved.

"What are the motives that impel me, as a person, to do this kind of work? Is it right for me as a person to pursue it?"—this on the one hand; and on the other "What are the motivating forces in society that encourage or canalize the pursuit of science, and its movement in this direction? Is it socially right, or socially desirable, that it should move in this direction? Is there a significant meaning—a morally compelling meaning—to the word *right* in this context?" These are questions at two different levels—and they must be separately assessed and not confused. The emotions and the values of the individual operate within and against a background of social convention and social practice that em erges out of factors of a different order from those from which individual judgements emerge.

Somewhere about 1933 I remember spending an evening with H. G. Wells who was a writer of considerable socio-scientific imagination. He had read my "Universe of Science" which had just been published. "I don't understand what you mean," he said, "when you write that science is a feature of social life—that scientists are socially activated. Surely a scientist pursues his work because he is interested—he is curious to find out." Here was a man who could write highly imaginative scientific romances, who could speculate about the kind of society in which one would live when science found its way into social practice, who could see what science evoked in society, but could not see what society evoked in science. And I am speaking of one of the better brains of that period.

To-day we are witnessing the same kind of difficulty. We are being told about scientists following this or that field of study because they are especially interested in it. Replace *because* by *and*, and we shall be nearer the truth. The nature of the distribution of financial support for scientific research has a tremendous effect on the scientific front that emerges. Finance operates at the social level. At the personal level the individual selects, on this front, the particular sector that attracts him. If, for example, no finance is available for pure mathematics, only mathematically gifted members of a leisured class will be

able to pursue it. Even a mathematician must eat. When therefore we talk of science being directed to peaceful or to destructive purposes we are driven back, in the main, on the question—where does the money come from which gives this kind of shape to the distribution curve of science ? We as individuals adjust ourselves to an overall pattern which is *largely* determined by factors other than our own intellectual interests.

It follows that when we are faced with individual moral choices or ethical problems on which we have to make a personal decision these problems have to be seen within the context of a given social situation, or arising out of a given political or financial policy. It is within that framework that the questions being discussed here are consciously or unconsciously being posed. We shall return to this point in a moment.

The next point to notice is implied in the assertion that there is *in principle* no difference between shooting an individual and mass destruction with an H-bomb. These words *in principle* cover a confusion of thought. Let us rather ask—what is the *same*, and what is *different* between individual killing and mass slaughter ? I need not waste time over this because the similarities and the differences become obvious. I can be shot here, now, but Manchester will scarcely turn a hair, but if an H-bomb were at this moment to burst here—what then ? No single shot at Sarajevo could to-day precipitate a world war, but an H-bomb dropped by an enemy on Manchester would spell the end of a great deal of what we mean by civilized social life. If, thereafter, human life survived, it would be genetically very different. Indeed it is precisely this distinction, experimentally demonstrated at Hiroshima and at Nagasaki, and now a focal fact in the imagination and the conscience of the younger scientists, which is responsible for the present discussion. To assert that there is no distinction *in principle* is to evade the real issue ; and be it noticed that the sharpness of the distinction stands out because of the human *and* social impact of the H-bomb. The sense of personal responsibility has widened out enormously because the very continuance of society and its sentient human content are swept into the horizon of moral decision.

War is an instrument of *international* political policy. Its purpose is to impose the political will of one State on another by wiping out as much of the industrial power and as many of the " enemy " as is necessary to force the enemy State to accept the political will of the other. All this is evident in the Imperialist wars of history, in the many colonial wars of the 19th century carried out by this country ; and it is implicit in the present international situation. A cynic might point out that those Governments most heavily armed for the pursuit of war on the international plane as an instrument of political policy are also most vigorously opposed to civil war as a political instrument. The State—their kind of State—is sacrosanct; its internal power must not be challenged in the same way as it may challenge the external power of another State ; and yet the history of the past forty years has shown how involvement in the one is linked with involvement in the other.

Why do I raise this issue of war being an instrument of international political policy ? The reason is simple. Society is a reservoir into which the findings of science are poured. As I have pointed out the direction of scientific activity is canalized—during peace and during war—in directions which are largely determined by financial supports such as State grants either through the D.S.I.R. or through universities, say for nuclear physics, by industrial firms with prospective orders for bombers or guided missiles, etc., seeking to build up research groups in these fields. During peace-time and during war scientific principles are formulated which directly or indirectly find their application both in peace and in war. Those who have to forge the immediate weapons of war naturally dip their hands into the social fund of scientific knowledge that has been accumulated, in order to produce the most efficient means for destroying the enemy. To expect anything less is to be foolish. The full power of science, to which all of us have contributed in some

measure, is brought to bear on this problem, whether we have contributed early or late, whether during peace or war. Who among us can stand apart and assert that we have not been involved in some degree ? Science is part of the creative experience of mankind, and when the international political crisis reaches its climax, and war becomes an instrument of policy, it is inevitable that these created products will be turned to destructive ends. Scientists—and others—provide the means that will inevitably be used to achieve the international political ends.

Once this is realized it becomes clear how illogical it is for anyone to say " I will not hold a rifle, or contribute towards atom-bomb research because it involves killing." He may of course take that attitude in order to call attention to a feature of his society that he dislikes. That is a different matter. He may for example dislike the fact that war is used as an instrument of international policy. He may say—as I think correctly—that war on the large scale at least has outmoded or negated itself in the sense that if it is resorted to in an Atomic Age it cannot possibly achieve its political objective. It can only involve mass social suicide. The position he cannot logically adopt however is tacitly to accept war as a possible instrument of policy, and at the same time object to or have scruples about the instruments of war, and their outcome. If you will the end in a situation in which no holds are barred, you will the means, and the consequences of these means. If you object to nuclear weapons, if you object to working on nuclear weapon research then in effect you are saying that you object to the political policy that emerges in nuclear warfare. Those who object to the mass destruction of human beings, but refuse to turn back to the political policy that implies it, are not looking at the problem with the same degree of objectivity as they use when examining a scientific problem. There seems to me no escape from this position.

But, it has been argued, there is a vital distinction that has to be drawn. There is such a thing as arming oneself for a defensive war and arming for offence. A defensive war is imposed on you by the other party, and you have no option but to prepare to resist, whatever the consequences. There are two points to be made in this connection. The human stuff of which armies are made has to believe that right is on its side. There never has been a war which was not " rationalized " to the extent that each side felt and knew that justice was on its side. Hitler's armies believed they were defending civilization against lower breeds of mankind. We felt and knew the opposite. In this sense all wars are defensive and therefore the word has no significant meaning. In the second place every military strategist of modern warfare knows that the consequences of waiting to be attacked are so devastating that offence is the only method of defence. If warfare is to be the arbiter of political decisions on the international field the defender must strike first, and the distinction between offence and defence disappears. It is unrealistic.

In the discussion so far I have endeavoured to deal with the matters raised without introducing any values explicitly or any ethical judgements of my own. The word *should* does not occur, nor the phrase *I feel*, which is usually a prelude to expressing a personal value. I have tried to be as objective as possible. There are, however, certain values inherent in scientific work. When we say we are being objective we are making an effort to abstract the truth in the situation from our feelings and judgements about it, eliminating ourselves as it were from the problem. The act of doing so ensures assent to what is being asserted, from others whose values are very different from our own. In science you can be certain that your sins will find you out. Finally, no scientific paper can get away with a falsehood. This in itself exposes a value—a supreme value, without which in the last resort Man cannot survive—the need to find and express truth. Science is in fact an organized social movement to express a truth-value-urge.

This is taken so much for granted that we are usually quite unconscious of its existence. We simply operate it. Are there then possibly other values that we tacitly operate

without realizing that they are present ? Indeed there are many, but there are strong social pressures that tend to turn the scientific worker from examining them. " Be a good Christian, a kind father and keep your nose to the scientific grindstone. That is all you know and all you need to know." If you see a well-paid job advertised in the national press—advertised say by an American firm—and there are now many such—why not take it ? To feed clothe and educate you, from the cradle to the stage of creative research, has involved the expenditure of a good deal of hard work by the producers of this country. Seen merely as a piece of material you represent a good solid piece of capital goods. Without so much as " thank you," you feel you are entitled to hand over all this invested capital, not yours but your community's, to a business enterprise in another state so that it may reap the benefit of the sacrifice of your fellow-countrymen ; and this because of a personal financial inducement. As soon as one glances at this problem one sees that it is cut across with values and value judgements that hardly ever see the light of day. The humorous side of it becomes apparent when one realizes that you are permitted to export this invested capital, which you represent in yourself, but you would not be permitted to export any ordinary material capital just as easily as that. In practice the state values you less highly than a corresponding piece of machinery. The same is true of course about the industrialist who says to the taxpayer, to the universities and to the technical colleges : " It is up to you to produce the creative machine that can carry through research. I will choose which one I want for nothing, but I undertake to keep it running effectively, just as I would any other machine in my factory. The only difference is that I would have to buy the latter." Again I am not expressing any judgement on these values. I am merely pointing out that our social customs are honeycombed with them, and we are usually unconscious of their existence. We take them for granted as part of the make-up of our society.

They have, however, a very special relevance to the questions under discussion this afternoon. When a young scientist asks himself the question " Shall I or shall I not take a job on guided missile research or on H-bomb research ? " he is really exercising his judgement on certain values implicit in the society in which he lives and from which he receives his nourishment. He is part of a society in which war—and to-day it is H-bomb and guided missile warfare — is still accepted as a means of resolving international political issues when they come to a crisis. He cannot contract out of the situation. He cannot jump out of his social skin. This is the given background against which he has to exercise his personal judgement. Merely to say " I as an individual will stand aside and take no part in it " is not only illogical because there is no " aside " on which to stand, but it is also ineffective because there are plenty others to take his place. To handle a social issue of this nature requires not only individual but also group activity. For myself, if I felt strongly about it, as indeed I do, I would try to find the kind of job in which I retained my right of criticism and freedom of speech, and I would actively support any public action that held out a promise of changing the practice and the values of the society in which I lived away from an acceptance of the principle that international disputes in the last resort must be settled by force of arms. If the structure of society and its social objectives lead inevitably to the acceptance of this principle then my opposition must be directed against that structure and these objectives. The problem you are raising this afternoon is as deep and as far-reaching as that.

Professor M. Polanyi : I shall not follow Professor Levy into arguments which do not come within the terms of reference of this meeting. He has discussed a great number of issues for which we are responsible as citizens ; but we are concerned here only with problems in which the scientist has a special responsibility, as distinct from other citizens. Yet I think I should say at

least one sentence to express my disagreement with him on these matters. I totally disagree with his assumption that the Government of this country could, merely by changing its policy, secure peace without rendering the country defenceless against the expanding imperialist power of communism.

I do not think I am competent to deal with the question whether anti-Americanism is sufficiently acute in this country. That, again, I think is not a point which concerns us here.

Turning to the question raised by the junior speakers, I shall try to deal with them in the light of historic situations in which scientists have been involved and have taken action in the recent past. I shall recall a number of cases in which scientists have acted as scientists and have thereby influenced or at least tried to influence the course of important events. With Professor Levy's permission, I will take my examples from America.

The first case is that of Einstein and Szilard, who in 1939 wrote to President Roosevelt asking him to entertain a project for making atomic bombs. The same initiative was taken by Professors Peierls and Simon in this country, but—for reasons which will become apparent in a moment—I want to follow up the American case here. Einstein and Szilard believed that the project of an atomic bomb was already being mooted in Germany and that it was important that we should anticipate its development there.

Our next date is March, 1945. Early in that month Szilard once more approached President Roosevelt. The memorandum which he submitted to the President has since been published. In it Szilard predicted in all essential detail the disastrous political situation which was to arise the world over through the completion of the atomic bomb, which Szilard rightly believed to be imminent. This time Szilard intervened against the use of the atomic bomb, though he had originally helped to initiate it.

Another important action on the same lines was the intervention of the Franck Committee. This Committee, formed under the chairmanship of the universally respected physicist James Franck, united the whole galaxy of great scientists who had taken part in the production of the atomic bomb. It was June, 1945—still a whole month before the first atomic bomb had been exploded in the U.S. The Committee headed by Franck sent a memorandum to the Minister of Foreign Affairs, Stimson, in which they pointed out the political consequences which would result if the atomic bomb, the completion of which they foresaw, were used against Japanese towns. They strongly warned against any such action. That report, too, has since been published, and its clear appreciation of the consequences that would follow from the use of the atomic bomb for purposes of mass destruction is most remarkable.

We have here two series of initiatives taken by scientists, one in 1939, the other in 1945. They were directed in opposite directions, because the circumstances had changed greatly between the two dates. In 1939 Germany seemed to be supreme; menacing to achieve dominion over the whole world. By 1945 Germany was defeated; the Russians were approaching Berlin from the East, the Allies from the West. So the same scientists who had originally initiated, undertaken and carried to success the construction of the atomic bomb, now intervened to stop it. They directly intervened in politics and asserted their opinion at the highest level to the effect that what they had achieved should be set aside.

I think they were competent in either case to act as they did. When I say that they were competent I do not mean that they were right, though I think they were also right in both cases. For in spite of the fact that I have a grave doubt about the morality of using an atomic bomb or a hydrogen bomb, I think they were right to initiate the development of the atomic bomb in 1939, and even more warmly do I support their later action of trying to prevent its use in the war, as the war then stood.

These interventions of the atomic scientists illustrate various points which are under discussion at this meeting to-day. In both instances scientists were intervening actively in politics because a rather unusual combination of conditions happened to prevail. Let me enumerate these conditions. First of all, the scientists were dealing here with *applied* science and not with any question whether the pursuit of *pure* science should or should not be undertaken or subsidized. Secondly, they were unable to address public opinion directly, because the subject they were concerned with was secret. Thirdly—and perhaps I should have put this second and not third—they were acting on the grounds of knowledge which they alone possessed. To sum up the three conditions : they were acting on the grounds of a knowledge of applied science which they alone possessed and which they could not make public. Since they could not make the general public politically responsible for the decision in question, by imparting their knowledge to it, scientists felt competent to intervene in the course of history, or, at any rate, to assume the highest degree of responsibility for influencing the course of history.

The next step taken by the same group of scientists in America again throws light on a question raised by our younger colleagues. In December, 1945, this group of scientists started the *Atomic Scientists' Bulletin*, a journal entirely devoted to what Mr. Lord told us to be the prime responsibility of the scientist, namely, to instruct the public. I lived through those days in close contact with my friends in America and I remember the great efforts they made to get their understanding of the situation created by the atomic bomb across to the public. I remember how they laboured through the *Bulletin* until they managed to get across a consciousness of the fact that the atomic bomb had brought about a decisive phase in the history of the world ; that it was not just another big bomb. They were accused of being timid and frightened little men because they suggested that the new weapon was a menace to the world, and they got support from no quarter. Yet they persevered, and finally won through.

The next thing these scientists did was no less significant. They tried to design and get established some international institution which would peacefully control these new powers. Again, we had the same group of people, anxiously working together. They produced the Acheson-Lilenthal Report of 1946, which was adopted by the United States in the form of the Baruch Plan for the international control of atomic energy. The scientists saw the world faced with two alternatives. The first was to stop the development of atomic energy altogether. That seemed quite impossible, for everybody attached great importance to its technical prospects. So the atomic scientists put forward what they thought to be the only other alternative. They said : " Let us have an international organization which develops the technical possibilities of atomic fission and at the same time produces solidarity amongst scientists and amongst the nations from which the scientists will come. This will be a guarantee that the developments will be peaceful and will also be subject to international control."

Here again, the scientists intervened in the field of international politics because they had a knowledge which, although it could conceivably be imparted to the general public, could not be imparted quickly enough. For the whole conception of this project was such that only scientists could readily appreciate it on the grounds of their own lives. It was based on the idea that scientists working together would become friends and would forget the mutual suspicion which divided them all over the world, particularly between communist Russia and the West. Suspicion was the fundamental problem which faced the world and the scientists wanted to solve it in the light of their professional experience.

As you know, the idea of peace, as conceived by the scientists, did not succeed. It would be outside my scope to examine why it failed. My point is that the scientists were competent to try what they did and that their effort was meritorious.

The next stage of my story brings me to the very heart of the questions of conscience raised in this meeting. Around 1951-1952 —I have not had time to look up the date, but I think I have it right—the great companionship of the American atomic scientists broke up. The group divided into two camps, led respectively by Bethe and Teller. Bethe, Szilard and a number of others wrote articles in the *Bulletin* about the hydrogen bomb, and forecast the possibility of producing hydrogen bombs of indefinitely larger size. Moreover, they wrote about the possibility of coating hydrogen bombs with a cobalt crust which under the effect of radiation would be transmuted into clouds of radioactive poison, spreading destruction all over the globe. Horrified by these prospects, they called a halt to their colleagues, asking that they should desist from any further work in the field of atomic weapon developments.

Teller took a different view. He said, " This new bomb will inevitably be produced somewhere, and it is wrong to allow the country to remain defenceless, by lacking the power to retaliate, when threatened—as it undoubtedly will be—by this weapon.

I believe that both sides were altogether competent to act as they did, and I will not tell you which of them I think to have been right. They were competent to judge this question as scientists, for it was a question of applied science, in which they had knowledge that the citizen necessarily lacked.

Contrary to what Professor Levy said, the influence of the scientists, intervening on these various occasions in public affairs, was enormous. They unanimously made up their minds in 1940 to start the atomic bomb project and they carried it to success, in an incredibly short time. Then they unanimously made up their minds in the opposite direction and again exercised great influence on the public.

They fell out between themselves, and were divided, as I told you, about the hydrogen bomb. The saddest result of this dissension was the dismissal of Oppenheimer. Yet both sides in this great conflict deserve to be honourably mentioned for their motives, though, of course, I share only those of one side.

I shall only touch briefly on some further examples set by the American atomic scientists. Lately, the *Atomic Scientists' Bulletin* became involved in the fight against MacCarthy, and also against MacCarran, the Senator who devised the ingenious policy which excluded me (of all people) from entry to the United States, as a Communist. I will not pursue this matter here. But I think that scientists had a special responsibility in opposing the mounting suspicion against scientists, and intellectuals in general, in the United States at this period of time.

This brings me back once more to an earlier period, immediately following the explosion of the atomic bomb. Until then, people had heard about scientists only in a very remote way. They were surprised when they were now told that they had to spend a lot of money and give it to the scientists without any questions asked, to spend it exactly as they wanted, this being the way in which science must be cultivated. We have it on record how some distinguished scientists have struggled—not altogether successfully—to explain this before Committees of the Senate to the legislators of the United States. This struggle has been continued by the *Atomic Scientists' Bulletin* ever since.

There is another important principle involved here. The scientists were competent in taking up this challenge because they were fighting for the proper organization of universities and were defending what they believed to be the true position of science.

Such is the record of American scientists in public action during the last 10-15 years. I must now say something about the historic development in this country, which underlies the questions both of Mr. Lord and Dr. Burkhardt. An intellectual situation arose here which never had arisen in America. It is indeed a local phenomenon which does not exist in other countries to any similar extent, with the exception of the Soviet Union.

There was a strong Marxist movement

here which raised the question of the responsibility of science, long before the problem of atomic energy was even dreamed of. This great movement started in 1930-35, achieving its first major public manifestation in 1938 with the publication of books on the social functions of science by Bernal, Hogben and Crowther. The Marxist theory of pure science as forming part of technology was a new interpretation of science, imposing a new kind of responsibility on scientists. It said that the scientist was responsible for the effect of his discoveries on the welfare of the community, and that he should therefore be subject to such public direction and central planning which would assure the community that his work led to the best advantage of the community.

Much of this theory was very curious and came as near emptiness as human speech can come. For you cannot plan what it is impossible to foresee. Let me give an illustration here. In January, 1945, I sat on a B.B.C. Brains Trust with Bertrand Russell and we were asked whether Einstein's Theory of Relativity had any practical effects. Well, we thought deeply—and talked about something else. For we could not imagine any practical application of relativity. But no more than five months later the first atomic bomb was exploded, for the construction of which the relativistic equation of $E = mc^2$ was fundamental, as it determined the amount of energy released in the process of atomic fission. The social planning of science would have required that as early as 1905, Einstein, when applying himself to the work which led to the discovery of relativity, should take into consideration that the equation $E = mc^2$ which he was about to discover might be used to plan an atomic bomb and to drop it on Hiroshima ! Nothing could be more absurd. And indeed, the whole idea of planning science for the welfare of society is completely absurd.

Yet the Marxist movement spread rapidly in Britain. In 1938 the British Association founded a new section for the Social Relations of Science. I do not know what that means, but the Section still exists. It is not very effective to-day, but at that early time, Sir Richard Gregory, Editor of *Nature*, a man of great intelligence and influence, was so impressed by its idea that he undertook to be its Chairman. The movement reached its culmination in January, 1943, when the Association of Scientific Workers held a mass meeting in London on the Planning of Science. I have the proceedings of this meeting here. There is some mention in it of the opposition which had grown up at that time. No names are given, but there is a reference in Sir Robert Watson-Watt's Presidential introduction to " anti-planners " who have contributed a lot to general gaiety—with other ironical remarks on these lines. I was one of those against whom these were directed.

I will tell you now of a most interesting stage in the history of this movement. In the summer of 1945 the University Grants Committee addressed itself to the Royal Society and asked the Society to convene its so-called Sectional Committees and ask them how science should be planned in this country for the purpose of filling gaps and avoiding overlapping. The Royal Society investigated the matter through these Committees and sent the result to the University Grants Committee, which circulated it to all the Universities. Some of them kept this circular in discreet concealment but others revealed it. I wish the whole proceedings could be placed on public record, because it is a most interesting example of an attempt at planning science nationally. It demonstrated the complete futility of the idea.

The question has again been raised here to-day whether we can do this kind of thing. In 1943 everybody was convinced that we can and must. We were told that we must completely change the way in which science is pursued in this country. Bernal said at the mass Meeting of the Scientific Workers that at last we had learned during this war how science should be pursued ; that we must never return to the old method. But actually nothing of the kind has happened. By December, 1945, at a meeting of the British Association's Section on the Social

Relations of Science held under Gregorys' chairmanship, I found to my surprise and joy that speaker after speaker deprecated the idea of a planned science. In fact, the whole idea was soon buried altogether. If you look at the Universities to-day you will see that science is pursued according to exactly the same principles as before the last War.

I suggest to you therefore that the question should be answered emphatically in the negative. We can do nothing—or anyway, so little as not to be worth mentioning—to guide the pursuit of pure science in a direction which will lead to the advantage of the community rather than the opposite. The simple truth is that we cannot foresee the technical outcome of scientific discoveries.

From this we can derive a fundamental positive principle, namely that pure science can be pursued only for its own sake. You must do it for the sake of acquiring knowledge, or else stop doing it altogether. This has been well known for the past 300 or 400 years, but it has been temporarily obscured through the Marxist theory of science. We must make absolutely sure of it now, once more.

It also follows, that applied science—on the contrary—can *not* be pursued for its own sake. Teller was greatly mistaken when he argued that hydrogen bombs had to be developed because science must inquire into all things unknown. It is nonsense to say that we must inquire into the pursuits of all possible purposes. It is for human beings to choose their purposes. What we are under obligation to pursue in all directions is knowledge for its own sake. That is what our University Charter requires of us when dedicating the University to the advancement and dissemination of knowledge.

I have said that the Marxist movement for the re-interpretation of science has passed away without a trace ; but that is not quite true. A shadow has been cast on the value and appreciation of pure science. For years " pure " science was printed in inverted commas even by *Nature*, to express a suspicion about the adjective " pure." Previously there had been " pure and applied mathematics " and " pure and applied physics " and " pure and applied chemistry," and nobody doubted the soundness of this distinction. Now suddenly it became dubious.

When we held an international conference in 1953 for the purpose of upholding the pursuit of pure science as an obligation of the human mind, we were attacked by Alex Comfort in *Tribune*. We were accused of being morally irresponsible and were told that we deserved no more respect than the oppressors of the geneticists in Russia (whom we had denounced) until we supported more practical and therefore more honourable interests.

I consider it a primary responsibility of scientists, whether themselves working in pure or applied science, to restore the appreciation of science as the pursuit of knowledge for its own sake.

More generally, I would recommend that we should always try to see whether the kind of problem with which we are faced in respect to our responsibilities had not already arisen in the past, and particularly, in the most recent past. We shall usually find that it has and, indeed, that it has arisen before in a more significant and therefore highly instructive form.

Discussion

Sir Eric James : I do not think anyone can feel that he has not enough problems to tackle. We have Cyprus on the extreme left and $E = mc^2$ on the right. I am not inviting you to discuss either. I am inviting you to raise any questions for the speakers. I do not guarantee that I will force them to answer !

Mr. G. H. Tattersall (*British Rayon Research Association*) : I have been rather disappointed that none of the speakers has made any positive contribution to the solution of the problems which beset young scientists at the present time. A great deal of time has been spent in enumerating the problems, which is a waste of time because everybody is quite familiar with them. I also think it fair to say that no speaker has declared his own exact position. That is

what I think is necessary. There has been little or no discussion of what philosophy should be used to establish ethical principles but in my submission it is impossible to have a satisfactory code of ethics without some philosophy underlying it. While you may develop an attitude to deal with present problems, what do you do when a new problem arises if you have not a basic philosophy on which to judge it ?

I see that Dr. Lord and Mr. Burkhardt are said to represent the younger scientist but I have no hesitation in declaring that they do not represent my views at all. In my opinion, the only satisfactory approach one can make is that of Christianity, and I believe that all ethical problems, even modern ones, can be considered and solved in the light of what Christ taught.

Turning to atomic energy, I am quite certain that Christianity absolutely prohibits the manufacture of the atomic bomb and I personally would not work on it. It has been said by some speakers that there is no difference in principle between an atomic bomb and a rifle, but Professor Levy has quite rightly said that there is a great difference. He did not, however, put his finger on the point, which I believe is that the atomic bomb is a quite indiscriminate weapon ; and there is a big difference between mass destruction and killing a person who is taking a specific action against you.

Nevertheless, in spite of this difference I think Christianity inclines one to the conclusion that war of any sort cannot be justified. I must also say that I disagree very strongly with Professor Levy's statement that individual action in refusing to work on the atomic bomb is useless. In saying that he condemns all martyrs, in any cause, who have stood alone for what they truly believe. He is right in saying that we can go further than passive resistance by taking political action, but that is not to deny the rights of the individual to stand up for his beliefs.

MR. K. M. GARDINER (*University of Manchester, Metallurgy Department*) : I was interested in the suggestion that the atomic bomb, and in particular the hydrogen bomb, was such a vastly different weapon from those used in the past that it posed different moral problems. I personally regard the aim of war as the destruction of the people of the opposing point of view, and surely the most efficient means of achieving that objective are the most acceptable means. If you agree with destroying those people who oppose your point of view, surely you agree with using the most efficient means of achieving that.

PROFESSOR LEVY : Are you asking whether I agree that we should destroy the people who disagree with us ?

SIR ERIC JAMES : You were asked whether you are opposed to war in any and every circumstance and, secondly, if you are not, why is the hydrogen bomb in particular morally wrong. Is that a fair statement ?

MR. GARDINER : Yes.

PROFESSOR LEVY : I am being asked a question, which, if I may say so, is quite abstract. Am I opposed to war ? I see war as a social fact, and I accept facts. I am, however, opposed to the encouragement of its continuance. Speaking as an individual I am prepared to stand up to that viewpoint, and indeed I have done so all my life. I do not know whether you think that is evading your question but that is as I see it. Arising out of this, since I understand a little about the consequences of an atomic war, it is incumbent on me to explain these consequences to others who can give me support in exercising social pressure. Mr. Tattersall complains that no one has said " I am a Christian." I do not approach the question in that preconceived way. I ask rather—what is the problem ? What can one do about it to make it consistent with one's values ? How do one's values arise and how do they change historically and socially ? How can I therefore sharpen my own values and those of others so that this problem may be more effectively dealt with ?

MR. BURKHARDT : In defence of myself

and Dr. Lord and in reply to Mr. Tattersall I must say that though we may not have appeared to offer any very constructive ideas, those which we put forward are held, possibly, by the majority of the community. He said that a code of ethics was impossible without a philosophy. The terminology seems a little confused, but I think he meant that a code of action was impossible without a set of principles behind it. I am not prepared to say, "I am a Christian and therefore war is impossible and out of the question." If he is prepared to say that war is out of the question, then clearly building an atomic bomb is out of the question. But unless one is an absolute pacifist one must admit the making of the hydrogen bomb, I feel. We have both stated our positions on this point.

MR. WORMSLEY : Am I to understand from Professor Polanyi that it is not much use bodies of scientists making a protest ? Does that mean that he feels that the whole thing has been written off ? Is it not possible that there has been some awakening of the social conscience ? Does he feel that it is possible that with the development of science there is also a development of the social conscience ?

PROFESSOR POLANYI : I think there is a continuous rise in the intensity of the demand for social justice. That is one of the great powers which sways us to-day. I was only trying to distinguish—as perhaps the audience are not so willing to do—the opportunities when the scientist *as such* can act effectively and competently. These occasions are not very frequent, because the conditions for it are rather peculiar. The Acheson-Lilenthal Report was one such an occasion when scientists could make far reaching, constructive suggestions in international policy. But to-day I feel that similarly far reaching and important suggestions, which I hope are not out of the question, will not come from the scientist. I think that Bertrand Russell, in his speech at the London Conference concerning the dangers of the atomic bomb, accurately defined this point and laid down the principle that to-day there is no such peculiar knowledge which only the scientist could use for discovering the conditions of peace. That task devolves to wider domains of civic conscience to-day.

MR. DONOGHUE : One important question raised to-day was, if it is wrong to make a hydrogen bomb, is it also wrong to take a rifle to kill your opponent in cold blood ? Professor Levy said there was a great deal of difference. I do not think that was ever true and I do not think it is true to-day. If we go back to the time when Duke William at Hastings told his archers to shoot, and they killed Harold, we see that they did not only kill one man ; they replaced a Saxon way of life by a Norman way of life. It had a most profound effect on the way of life of the people of this country at that time.

If, to-day, someone takes a rifle and shoots me, or even Professor Levy, it is not different from killing the king. In this country and the United States, in which we elect the Government, we are the Government and we are the country. If we kill someone who is the Government of his country, are we not altering the way of life as much as the Saxon way of life was altered when the arrow killed Harold, King of the Saxons ? There is no difference whatever between the hydrogen bomb and killing your opponent with a rifle.

MR. N. CLARKE (*The Institute of Physics*) : There appears to be much concern about the moral difference, if any, between the use of a hydrogen bomb and the use of rifles and arrows. I do not wish to pursue the question whether there is any difference "in principle," whatever that means ; the word "principle" is used too often and too loosely, without a clear statement of the principle to which one is referring.

Personally, I am quite sure that the use in any circumstances of a hydrogen bomb is morally wrong. If someone now says to me, "Then, to be consistent, you must not shoot arrows into people's eyes," I am certainly prepared to consider his argument. But I am not prepared to consider the argument the other way round ;

that, if I were to say—which I do not—that there is nothing wrong in shooting arrows into people's eyes, I must therefore accept the hydrogen bomb.

I cannot believe that there is anybody in this room who would readily agree to be the actual user of one of these nuclear weapons. I suggest that the most profitable approach to this question is to repudiate firmly what we know to be horrible and to agree that on moral grounds this is a weapon which is both horrible and unacceptable. Whatever other conclusion one draws from that decision depends, as Professor Levy has said, upon one's personal values.

In my opinion the most helpful thing said this afternoon was the contribution of Mr. Tattersall. I suspect that many people came to this meeting hoping for answers to moral problems. But the most important thing we can say is that the only valid and satisfying answer to a moral problem is the answer that has been worried out for oneself, perhaps after much mental and spiritual difficulty. All we can do here is to try to indicate to others how we may have approached our own solutions. Like Mr. Tattersall, I speak as a Christian, and I agree with him that to speak of ethics without reference to a basic philosophy or religious belief is not of much value.

Professor Levy seemed to me to equate morality and politics ; he thinks in terms of the morality of society, whereas Mr. Tattersall and I think primarily in terms of personal ethics. I accept Albert Schweitzer's view that the ethics of an individual will always be in conflict with the ethics of society, which will be at a lower level. Yet even Professor Levy, presumably in an un-Marxist slip, referred to individuals who try to change the values of society, although in countries more sympathetic to Professor Levy's political views the consequences might be harsh. He recognizes the contribution which may be made by the individual who insists upon maintaining his own morality and will not accept the morality of society, even though he knows that severe penalties may be imposed upon him. The individual has to be prepared to stand against society in order to try to be true to his own ethical standards and, as Mr. Tattersall has said, progress has often come that way.

I particularly hope that no one will be misled by what an earlier speaker said about the small contribution which we as individuals can make. This argument is often put forward as an excuse for failure to make a moral decision. Of course the contribution is small—but the decision is vitally important. If somebody were to ask a young scientist, " Are you sure you want to take this job, even though there is something morally objectionable in it ? ", he might well reply, " My contribution is so small that it would not make any difference if I refused to do it." I doubt whether he would often give the equally logical answer, " My contribution to the development of guided missiles or atomic weapons is so small that it is not worth making." Young men who consult me about careers are often interested in any job that will pay them adequately and, preferably, will get them out of military service ; in too many cases they do not seem to me to care at all what it is they are to do. I do not think they would be hostile to the moral values I accept—they are just indifferent. That, I believe, is the terrible tragedy of our modern society.

We must be responsible for our own consciences, trying to behave in accordance with them. Whether our contributions be small or great, that is what we should do—but who can deny that the results could be very great if more scientists were to take the view that they would no longer work in fields of scientific research that were morally objectionable.

Those who think as I do believe that the maintenance of one's personal ethical standard is what primarily matters, although we recognize our responsibility to contribute to the advancement of the standards of society, as Professor Levy has suggested.

MR. A. E. DE BARR (*Shirley Institute*) : I should like to put a fairly simple question.

Some people may feel for reasons of conscience that they will have nothing to do with nuclear weapons, some feel that they ought to take part in their production, but the vast majority lie somewhere in between.

Professor Levy pointed out, and we all know, that the pages of the journals are filled with advertisements for all kinds of jobs. Is it sheer escapism to avoid those jobs with military implications and to turn to things directly useful, industrially or socially ? I am not suggesting that these things do not have indirect military implications, but their direct contribution, I suggest, is to the immediate benefit of mankind. Is it escapism to take that point of view ?

Mr. Mason : I should like to support what has been said about the responsibility of each individual and to add to it. It is not the individual by himself who has to decide these things. It must be done with God's help. If each of us seeks His will, then we can answer each and every question which comes to us. It is up to each individual to do his best to get the highest moral standards he can and find God's will for himself.

If everyone said, " Society cannot do this," we should get somewhere.

A Speaker : I am a miner and a man in the street. I came here to-day thinking the scientists would help me. You have great power—atomic energy ; you are going to build tremendous power stations. Why do you not get on with it ? It would make my life much less hard. Men are working and sweating where they need not work and sweat. Science can give us power to relieve us of this grind. That is your real purpose in life—to harness the power which has been discovered by your brilliant brains, and give us a new way of life.

Sir Eric James : I will ask the two senior speakers to reply in two minutes each.

Professor Levy : Within my two minutes, I will confine myself to one point. There is a misconception in the minds of many people here about the possible outcome of this afternoon's discussion. An ethical question is done which involves values and judgement. As far as possible a scientific question is presumed to exclude personal values and judgement, and attempts are made to keep them out of the picture, and to discover those things in Nature which are valid for individuals with different kinds of values and judgements.

When we met this afternoon to discuss certain ethical problems, we approached them from a reasonable, rational, intellectual standpoint from a scientific standpoint. We cannot give you an answer to the ethical problems which you have, and anybody who came here to get a ready-made answer to the question : " Shall I, as a ploughman, carry on my job since I know that the food I am producing goes to feed those scientists who are making hydrogen bombs," will be disappointed. I am not answering that. All I can do is to point out that an individual who for example is working in agriculture, apparently far removed from the production of a hydrogen bomb, is helping to carry through the activities of a society which is producing hydrogen bombs and which is moving towards self-destruction. After that, you must use your values and judgements to decide your individual attitude to the question.

Mr. Clarke seemed to imply that I, as a Marxist—and I am—cannot have a view point which suggests that the individual and his ethical outlook can have any effect on society : rather, that he mechanically reflects the attitude of society. That is a complete travesty of Marxism. What am I doing here to-day ? Am I a mirror which is reflecting the ethical attitude of society or am I an individual trying to change your outlook ? Surely the latter. There is no other way in which it can be done.

I have of course to ask myself where I get my outlook : (*a*) from the climate of opinion in the community in which I have been brought up ? (*b*) from the particular experiences which I have had which enable me to analyse them in a different way from that in which others analyse theirs, because they have had a different experience from mine ? (*c*) what is there in common between mine and those of other people—people with

different experience—which enables us jointly to analyse the relationship between the climate of opinion and values of the community and my values ?

I have a personal ethic which I am here trying to operate. I recognize that I have drawn nourishment from the community. I recognize that my view point differs from that generally accepted. I recognize that I must try to transform the climate of opinion so that the community as a whole comes to see that the analysis which I am making is something which can be put into operation and thus make life secure and more valuable in the future by eliminating this movement to mass destruction. That is my attitude. It means that the individual has an ethic and the community has an ethic, and there is this interplay, this interaction between the two. They move and develop together.

PROFESSOR POLANYI : This is a rather solemn occasion for me because I have to say some words which may harshly oppose a speaker whom I respect and to whom I should like to offer every consideration. I do not agree that the purpose of this University is to advance the opulence of society. Though the speaker is a miner I do not think that he himself is insensible to the revelations of science, that he has no curiosity about the way our planet is turning round its axis and wandering round the sun ; about the history of the universe and the origin of species ; or about the nature of life and the workings of the mind. If he is not very interested, his sons will be. We are here to serve this noble interest by the pursuit of knowledge and the dissemination of knowledge. When we cease to serve this interest we cease to be a university.

I did not think it my business to say it here, but I for one find myself in the camp of Bethe, who objected to the development of the hydrogen bomb. I think the argument so ingeniously presented to us by Mr. Clarke is perfectly true. If you apply the principle that everything is but a matter of degree, there is nothing you cannot justify and there is no objection you cannot eliminate ; there is no crime you cannot justify and no conscience you cannot destroy by this argument. Darwin has shown that the differences between the butterfly and the elephant are only a matter of degree, yet the two are quite different creatures. We should avoid such specious arguments and rely on a more genuine sense of our true moral convictions.

SIR ERIC JAMES : The programme says that I shall say a few words in summing up, and they will indeed be very few. It is obviously an extremely difficult subject to sum up, particularly as the speakers attacked it from very different angles. I have felt rather like a centre-forward, with the two inside forwards going roughly in the same direction and the two outside forwards kicking at goals which were somewhat different. Part of the difficulty arises from the variety of the problems which we have been discussing. The number of ethical problems with which the scientist has been faced this afternoon has been legion. The bomb has dominated all our thoughts, as it tends to do, but there have been other problems ; what kind of research should the scientist do ? Should he not do research at all ? Should he go into a backward and despised occupation like teaching ?

What emerges as one central theme is whether the scientist to-day has any more responsibility than anyone else. On the one side, you have the view that on the whole he has not, except as a citizen. You have the view which Professor Levy put forward, I am sure very eloquently, that the scientist's activities, and to some extent his values, are conditioned by the society in which he lives. The circumstances of research, the amount of money research requires, the need for these enormous machines, the need for investment of great capital sums, inevitably raises the question of the wishes of society. It is these which are conditioning our scientific activity, and to a great extent the scientist can only function as a member of society. That is the argument.

I wish myself that Professor Levy had always been more careful in his use of the

words, "society," "state" and "community," because those three terms are not synonymous. It would be worth while for us all to think about the difference. Nevertheless, there is a real point in the argument.

If you do not like the means, it is argued, the way you must operate is to determine the policy. You have to alter the policy of society which is conditioning the situation, and you will alter that according to your individual values. There, again, was another interesting point on which Professor Levy touched, as to whether a scientist is concerned with values or not. He said science was not concerned with them, and yet many here would say that every time we use an argument involving choices we are making a value judgement. That is a very important point. Nevertheless, Professor Levy's view is that our activities are conditioned by the society in which we live and the only moral thing for us to do is to alter society.

On the other hand, we have the individual responsibility of the individual scientist, *qua* scientist—the responsibility of enlightenment. The scientist, because of his knowledge, is the only man who knows where we are going in the modern world and he has to say so, whether as a publicist or in a humbler way as a teacher. It has been pointed out that no scientist is free from this individual responsibility.

I think that the bomb has dominated our thoughts this afternoon, as it dominates the whole of our thinking about most things to-day, too much. We are all involved, whether we are doing nuclear research or not. In fact, it seems to me that none of us engaged in scientific work, or, as Professor Levy pointed out, even the agriculturist, can contract out of this moral obligation with which we are faced. Mr. Tattersall's interesting contribution brought this to my mind—that the simple straight-forward thing for the scientist to say was, "I am a Christian ; therefore no hydrogen bomb. Because there are other things on which the scientist can work." But can we dissociate ourselves? Even the schoolmaster who is educating people—who might work on hydrogen bombs—cannot dissociate himself from this personal moral responsibility.

Another point, which has not been mentioned but which raises this personal responsibility of the scientist, is a point for the future. As the years go by a greater and greater proportion of the ability of the country will be associated with scientific work, and therefore if rational moral judgements are to be made it is all the more vital that the scientist should be a moral person.

Finally, you get to the point which Professor Polanyi put, that the scientist has this supreme, individual, moral responsibility to defend truth ; truth which transcends nationality and which even views with equanimity the export of scientists. I was disappointed to hear Professor Levy being nationalistic about that ! Here we have the scientist who believes in some great truth which it is our greatest duty to serve. Professor Polanyi told us that the scientist has a great, individual, moral responsibility to defend that ideal.

I will not attempt to decide between these two points of view. What I think has come out is this very important fact, which I think is fundamental to all moral discussion —and Mr. Clarke put it better than I could : that there are no simple answers to problems like this. The encouraging thing about a meeting like this is that you have a gathering of scientists who realize that they are not only working on transistors; they are also individuals who, as scientists, have a moral responsibility ultimately to say, what is the object of the exercise ? How does this activity square with the general body of the ethical beliefs which I hold ? Is it defensible in those terms ?

They will often answer that question wrong, as we all do, but the great value to humanity and the great hope for progress of the human spirit is that the question should be asked.

I am personally very grateful to The Institute of Physics for making it possible to have this discussion and to bring this problem into the minds of all of us. Secondly, we are all very grateful to the four speakers

who have given up their time this afternoon to put before us with such absolute sincerity points of view which necessarily differ about these fundamental questions. We have all to think about these problems and wrestle with them for ourselves.

Branch News

Malayan Branch

The Inaugural General Meeting of the Malayan Branch of the Institute was held in Singapore on May 9, 1956. Mr. C. G. Webb (*Fellow*), Head of the Physics Department of the University of Malaya, was elected Chairman of the Branch and Dr. Thong Saw Pak (*Associate*) was elected Honorary Secretary. Three other members of the Branch Committee were elected : Dr. B. W. Purslow (*Associate*), Mr. Hong Yuen Sen (*Associate*) and Mr. J. Lee (*Student*). Following the business meeting the film " The Handling of α- β- and γ-active isotopes " was shown.

Prior to the meeting, there had been a display of instruments for the detection and measurement of radioactivity. One of the press photographs taken at the meeting is reproduced here.

Mr. C. G. Webb (left) and Mr. James Lee

Scottish Branch

Dr. A. R. Boyle (*Associate*) has succeeded Mr. T. H. O'Beirne (*Fellow*) as Honorary Secretary of the Branch. Mr. O'Beirne has been Honorary Secretary for three years.

North Eastern Branch

Mr. J. E. Caffyn (*Fellow*) has succeeded Dr. N. Thorley (*Fellow*) as Honorary Secretary of the Branch. Dr. Thorley has been Honorary Secretary since the formation of the North Eastern Branch over six years ago.

Meetings of the British Nuclear Energy Conference

Constituent Societies :
THE INSTITUTION OF CIVIL ENGINEERS, THE INSTITUTION OF MECHANICAL ENGINEERS, THE INSTITUTION OF ELECTRICAL ENGINEERS, THE INSTITUTE OF PHYSICS AND THE INSTITUTION OF CHEMICAL ENGINEERS

Members of the Institute are invited to attend the following meetings.

A Symposium on

" Calder Works Nuclear Power Plant "

will be held on

November 22 and 23, 1956

at the Institution of Civil Engineers.

The programme is as follows. Discussions will take place at the end of each Session.

Thursday, Nov. 22 — Session 1 : " *Introduction and General Design* " — 10 a.m.
Chairman : SIR JOHN COCKCROFT

Paper		Authors
Conference Procedure		SIR JOHN COCKCROFT
1.	*British nuclear power programme*	SIR CHRISTOPHER HINTON
2.	*The design study*	R. V. MOORE and B. L. GOODLET
3.	*The Calder Works Plant*	R. V. MOORE

Thursday, Nov. 22 — Session 2 : *Technical Research Problems* — 2 p.m.
Chairman : SIR JOHN COCKCROFT

4.	*Experimental heat transfer work*	P. FORTESCUE and W. B. HALL
5.	*Experimental physics*	P. MUMMERY
6.	*Shielding design*	W. BONSALL and C. HORTON
7.	*Basic design of reactor*	G. PACKMAN and B. CUTTS
8.	*Early metallurgical problems*	L. M. WYATT and R. A. U. HUDDLE
9.	*Metallurgical developments for Calder Works*	L. GRAINGER and A. B. MCINTOSH

Friday, Nov. 23 — Session 3 : " *Engineering Design* " — 10 a.m.
Chairman : MR. W. L. OWEN

10.	*Design and construction of reactor vessel*	G. BROWN, M. NOONE and R. F. BISHOP
11.	*Uranium fuel handling*	K. DENT and G. W. GROSSMITH
12.	*Design of important plant items*	A. T. BOWDEN and G. H. MARTIN
13.	*Steam cycle analysis*	W. R. WOOTTON
14.	*Design and construction of heat exchangers*	H. MORRIS and W. R. WOOTTON

Friday, Nov. 23 — Session 4 : " *Light Engineering and Electrical* " — 2 p.m.
Chairman : MR. J. ECCLES

15.	*Equipment for control of the reactor*	J. H. BOWEN and S. A. GHALIB
16.	*Detection of faulty fuel elements*	E. LONG, J. M. LAITHWAITE and K. W. CUNNINGHAM
17.	*Reactor control and instrumentation*	R. J. COX and K. R. SANDIFORD
18.	*System control and protection*	J. H. BOWEN and E. ANDERSON

Friday, Nov. 23 — Session 5 : " *Future Developments and Summary* " — 5.30 p.m.
Chairman : SIR JOHN COCKCROFT

19.	*Future developments of gas-cooled reactors*	R. V. MOORE
20.	*Summary of proceedings*	SIR CHRISTOPHER HINTON

Admittance will be by registration, and a charge of £1 will be made towards the cost of advance proofs. Application forms are obtainable from the Secretary, B.N.E.C., 1-7 Great George Street. The papers and discussions will be printed in full in the *Journal of The British Nuclear Energy Conference.*

The Institute's Journals

PRINCIPAL CONTENTS OF THE JULY, 1956, ISSUES

Journal of Scientific Instruments: Volume 33, No. 7

SPECIAL ARTICLE

The language of instrument calibration and performance. By K. M. Greenland, F.Inst.P. (*The British Scientific Instrument Research Association, Chislehurst, Kent*).

A critical discussion is presented of the terms used in describing the establishment of instrument scales and the performance of measuring instruments. Examination of a number of vocabularies and of unrecorded usage shows that many of the important terms have more than one meaning. Arguments are put forward in support of certain unique definitions consistent, wherever possible, with the original sense of the words. The discussion takes as a basis the new definitive glossary compiled by the British Standards Institution (B.S. 2643 : 1955).

PAPERS

A method for rapid analysis of very small gas samples. By H. E. Lewis and O. C. J. Lippold (*Department of Physiology, University College, London*).

An apparatus is described for the analysis of small samples of gas (0·1–0·001 ml.). A small bubble of the sample is injected into water in a chamber formed by two horizontal parallel plates. This bubble assumes the shape of a disk, which can be measured, since the volume is then proportional to its cross-sectional area. Convenient methods of optical measurement and recording are described. Analysis is made by the introduction into the chamber of suitable absorbents. Reference is made to some of the uses of this apparatus.

A simple differential pulse height analyser. By E. C. Park (*Department of Physics, The University of Birmingham*).

A single-channel, pulse height analyser is described. Descrimination is by germanium diodes. Only three valves are used : two double triodes in trigger circuits and another in an anti-coincidence arrangement. The analyser will accept positive pulses of shapes normally encountered with scintillation and proportional counters, and has an accuracy comparable to that of other recently reported circuits. The lower level of the discriminator can be varied from 0–60 V and the channel width from 0–20 V. Bias voltages are read directly on a meter. Zero or threshold adjustments are not required. Both differential and integral output pulses are available.

A sensitive and stable nuclear induction head. By E. A. Richards, G. Phillips, and W. K. Campe (*Signals Research and Development Establishment, Christchurch, Hants*).

Details are given of the construction and performance of a " crossed coil " induction head, for the detection of nuclear magnetic resonance in 0·1 cm³ specimens, in which the condition of maximum sensitivity is achieved through the operation of a single manual control. The simple method of construction provides, at the optimum setting, a decoupling of 80 dB between the coils which remains constant to within 0·4 dB over a period of a week.

A constant-volume, membrane, interferometric microrespirometer. By B. M. Turner (*Turner Lighter Spares and Components Ltd., Hendon, London, N.W.4*).

Gas enchange in the 7–10 mμl. air film enclosed between a cover slip and the end of a capillary tube closed by a thin collodion membrane is measured by the external pressure required to restore the membrane to its constant volume position parallel to the slip. Membrane displacement is observed by two-beam reflexion monochromatic interferometry. The membrane separates each chamber from a common manifold leading through a central spherical joint to a conventional Warburg manometer. Rotation about the joint brings each chamber successively under the microscope. No membrane calibration is required. The capillaries are embedded vertically in an aluminium block for temperature uniformity. Preliminary results show a sensitivity of 1–10μμl.

An instrument for the automatic recording, of hysteresis loops. By D. C. Gall, F.Inst.P., and J. D. Watson (*King's College, University of London*).

The paper describes an apparatus designed to plot automatically the hysteresis loops of samples of ferromagnetic materials. The cycle of magnetization is carried out in about fifteen minutes. The induction in the specimen is measured by electro-mechanical integration of the induced electromotive force in a search coil, by a miniature electric motor having accurate proportionality between speed of rotation and applied voltage. The apparatus so far has been applied only to ring specimens in which the value of magnetizing force is directly dependent on the magnetizing current. The magnetizing force, in the case of

the ring specimens used, is measured in terms of the voltage drop across a shunt carrying the magnetizing current. Novel features of the design are the method of integrating the search coil voltage, and the incorporation of automatic control of the magnetizing current, with the object of maintaining the search coil electromotive force within the range of the integrator motor at all times.

The omegatron as a leak detector. By R. L. Bell (*Services Electronics Research Laboratory, Baldock, Herts*).

The omegatron, a radio-frequency mass spectrometer, has been applied to the detection of very small leaks using the helium probe technique. Although intrinsically of similar sensitivity to the conventional magnetic sector mass spectrometer, its effective sensitivity can be very much increased by reducing the speed at which the leak and leak detector combination is pumped, an operation which is not feasible with the usual mass spectrometer. By this means leaks of 10^{-11} l. mb/s are readily found. The limiting sensitivity appears to lie in the 10^{-14} l. mb/s region. A simple omegatron constructed for leak detection is described, and precautions to be taken in the use of helium mentioned.

An apparatus for producing air of controlled relative humidity for hygrometer calibration and testing. By L. A. Cram. (*The Imperial Tobacco Co. [of Gt. Britain and Ireland], Ltd., Bristol 3*).

Wet and dry air streams are mixed in variable proportions to produce air between 30 and 85% r.h. This humidity is stabilized by automatic control using an electrolytic hygrometer. Calibrations reproducible to better than 0·2% r.h. can be carried out quite quickly.

A high pressure methane ionization chamber. By F. J. M. Farley (*Atomic Energy Research Establishment, Harwell, Berks*).

An ionization chamber, 2 in. in diameter and 8 in. long, using quartz-Invar seals, is described. Filled with fractionally distilled methane to a pressure of 40 atm and operated at 12 kV the chamber has an efficiency of 10% for counting 3 MeV neutrons and a collection time of the order of 1 μs. Detailed information on counting efficiencies and delay times is presented.

LABORATORY AND WORKSHOP NOTES

Adaption of a gas and water union to high vacuum circuits.
By A. D. Cassell *and* D. A. Hockly.

A parallel-spring cross-movement for an optical bench.
By R. V. Jones.

The use of a ball-point recording system on the Dines anemometer.
By E. A. Cohen.

A light interrupter of continuously variable on-off ratio.
By T. P. Brody.

A dual-purpose specimen spinner for transmission and reflexion X-ray diffraction.
By P. N. Bestelink *and* D. R. Holmes.

A tapered plug vacuum valve.
By H. R. Moore.

The infra-red spectrometer as a non-dispersive instrument.
By R. Burt *and* G. J. Minkoff.

CORRESPONDENCE

A capacitance-resistance hygrometer.
From J. MacDowall; C. L. Cutting, A. C. Jason *and* J. L. Wood.

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SPECIAL ARTICLES

The International Temperature Scale and a redefinition of the Kelvin Scale. By J. A. Hall, F.Inst.P. (*National Physical Laboratory, Teddington, Middlesex*).

The Tenth General Conference of Weights and Measures has accepted a redefinition of the Kelvin (absolute) temperature in terms of one fixed point, the triple point of water, to which a value of 273·16°K has been assigned. The International Temperature Scale continues to be defined in terms of 100° between the ice point (0·0100°C below the triple point of water) and the steam point. The relationship between the scales and the approved designations are set out in a table. Work is being carried out with a view to future improvement of the international scale. It is hoped that it may be found possible to extend the range covered by the resistance thermometer both above and below its present limits of 630·5°C and −182·97°C, the latter temperature being the present lower limit of the international scale. If the resistance thermometer scale can be carried up to 1063°C (the freezing point of gold), it will be possible to eliminate the thermocouple as a standard instrument and so improve both the continuity and reproducibility of the scale.

Conference Report

A symposium on magnetism — London, September, 1955.

The Electronics Group of The Institute of Physics held an informal symposium on recent developments in magnetism at the Institute's house on September 23 and 24, 1955. Speakers from university, government and industrial research groups took part in the conference and the subjects discussed ranged from some latest advances in theoretical studies, to the application of magnetic materials to computor systems.

Papers

The tensile strength of coal. By C. D. Pomeroy, A.Inst.P., and W. T. A. Morgans (*National Coal Board, Mining Research Establishment, Isleworth, Middlesex*).

Apparatus is described which has been developed for the measurement of the tensile strength of coal by bending thin strips. Measurements on four coals show that the strength depends on the type of coal and on the direction of loading relative to the bedding planes.

One coal has been studied in some detail and the tensile strength is shown to decrease with increasing size of specimen. The effect is attributed to the increased probability of finding in larger specimens a weakness which imparts a low strength. It is estimated that for a given size of specimen the tensile strength is of the order of one-tenth of the compressive strength. Further, it has been found possible to rejoin broken strips of this coal so that up to ten successive tensile tests can be performed on a single strip, thus enabling the distribution of the weaknesses to be studied. In general, there is an increment of strength between successive breakages, and after ten breaks the tensile strength is roughly double the value obtained at the first break. This method of studying distribution of strength does not appear to have been used previously, although it is likely to have applications to many other brittle materials.

Apparatus and techniques for the application of a waterflow system to the study of aerodynamic systems. By E. F. Winter and J. H. Deterding ("*Shell*" *Research Ltd., Thornton Research Centre, Chester*).

The study of fluid flow in such gaseous systems as combustion chambers and furnaces is of value in the design and subsequent operation of the equipment. Useful information may be obtained from flow visualization in these systems under constant density conditions, even though in practice considerable density changes occur. Hydraulic models are then found to have distinct advantages over air models.

Apparatus has been developed by means of which the flow of water may be studied in transparent models of the simulated air systems. The flow is rendered visible by plastic tracers, of similar density to water, which are illuminated by continuous filament lamps, long-duration electronic flash lamps or vapour discharge lamps, according to the information required. Selected parts of the flow field may be observed by means of a narrow, flat beam of light directed through the appropriate section of the model. Semi-quantitative records of flow components may be derived from photographs obtained with the flash illumination. Individual tracers may be observed by selective illumination involving an ultra-violet light source and fluorescent tracers.

The subject is treated from a wholly practical point of view. Details of the apparatus and techniques are given, with examples of some of the types of information obtainable, and the elementary requirements for similarity with aerodynamic systems are stated.

The "ploughing" contribution to friction. By R. T. Spurr (*Ferodo Ltd., Chapel-en-le-Frith, Stockport, Cheshire*).

When a hard surface is slid over a softer surface part of the frictional resistance is due to the force required to plough asperities of the harder surface through the softer. It is shown how this ploughing contribution to friction can be obtained for hard steel balls and wedges sliding on soft metals.

Klystron oscillator noise theory. By R. L. Bell (*Services Electronics Research Laboratory, Baldock, Herts*).

Results are presented of calculations on the amplitude and frequency fluctuations generated in a floating-drift-tube klystron oscillator by thermal noise in the cavity and current and velocity noise on the electron beam. Current fluctuations at the oscillation and harmonic frequencies are found to be the main source of frequency and amplitude modulation noise. At the very lowest modulation frequencies flicker noise in the beam will take over as the source of a.m. noise. The predominant f.m. source in this region is uncertain. Methods of reducing the noise are pointed out.

The display of logarithmic Langmuir probe characteristics on a cathode-ray oscillograph. By A. R. Johnston (*Physics Department, The Queen's University of Belfast*).

A new method for displaying Langmuir probe characteristics on a persistent screen cathode-ray oscillograph is described. The cathode-ray oscillograph traces are recorded on microfilm. A comparison is given of the values of some discharge parameters obtained by this method and those found by measuring the probe current with a galvanometer.

Correspondence

Measurement of the electrical conductivity of the oxide-coated cathode.

From T. B. Tomlinson *and* R. E. J. King.